# Abstract

Bubbly turbulent flows occur in a variety of industrial, naval and geophysical problems. In these flows, the bubbles in the flow interact with turbulence and/or vortical structures present in the continuous phase, resulting in bubble motion and deformation, and at the same time modifying the turbulence and/or vortical structures. Despite the fact that this has been a subject of interest for some time, mechanisms of bubble break-up due to turbulence and turbulence modulation due to bubbles are not well understood. To help understand this two-way coupled problem, we study in this thesis, the interaction of single and multiple bubbles with vortical structures; the thesis being broadly divided in to three parts. In the first part, we study the interaction of a single bubble with a single vortical structure, namely a vortex ring, formed in the continuous phase (water). This may be thought of as a simplified case of the interaction of bubbles with vortical structures in any turbulent flow. We then increase the complexity and study the interaction of a single bubble with naturally occurring vortical structures present in a fully developed turbulent channel flow, and then finally to the case of a large number of bubbles injected in to a fully developed turbulent channel. The bubble motions and deformations in all three cases are directly imaged using high speed visualizations, while the flow field information is obtained using time-resolved Particle-Image Velocimetry (PIV) in the first two cases, and from pressure drop measurements within the channel in the latter case.

The interaction of a single vortex ring with a bubble has been studied for a large range of vortex ring strengths, represented in terms of a Weber number (We). We find that in all cases, the bubble is first captured by the low pressure within the core of the ring, then stretched azimuthally within the core, and gradually broken up in to a number of smaller bubbles. Along with these bubble deformations, the vorticity within the core of the ring is also modified significantly due to bubble capture. In particular, at low We, we find that the core of the ring fragments as a result of the interaction resulting in a large reduction in the enstrophy of the ring and its convection speed. In the second part of the thesis, interaction of a single bubble with naturally occurring vortical structures present in a fully developed turbulent channel is studied. In this case, single bubbles of different sizes are injected either from bottom or top wall into a channel at Reynolds number of about 60,000. We study the

trajectories of the single bubble, and also investigate the effect that such bubbles have on the naturally occurring vortical structures present in these flows. The injected bubble is found to have three broadly different types of bubble paths when injected from the bottom wall, which are sliding along the wall, bouncing motions and vertical escape from the vicinity of the wall. Even at the same bubble diameter D_b and channel flow Re, we find that different realizations show considerable variations, with all three bubble paths being possible. PIV measurements of a bubble captured by a naturally occurring vortical structure in the flow, shows a more rapid decrease in enstrophy compared to naturally occurring structures in the absence of bubbles, as seen in the interaction of a bubble with a vortex ring. We also find that the bubble can interact with multiple vortical structures, depending on their strength and spatial distribution in the flow, resulting in a complex bouncing bubble motion. In the third part of the study, a large number of bubbles are injected in to the channel through porous plates fixed at the top and bottom channel walls. The main parameters here are the channel Re, bubble void fraction (α) and the orientation of injection. In this case, in addition to bubble visualizations, the pressure drop through the channel is measured at different vertical locations. These measurements show large vertical variations in the measured pressure drop due to the presence of bubbles. The overall drag reduction in these cases is obtained from an integral of the pressure drop variation along the vertical direction. The visualizations show a number of bubble dynamics regimes depending on the parameters, with possibilities of both increased and decreased drag compared to the reference no bubble case. From simultaneous measurements, we relate the variations in drag reduction to the different bubble dynamics regimes. We find that at the same void fraction (α), the drag reduction obtained can be very different due to changes in bubble dynamics regimes caused by changes in other parameters. Top wall injection is observed to give good drag reductions over a wide range of flow Re and α, but is seen to saturate beyond a threshold α. In contrast, the bottom wall injection case shows that drag reduction continuously increases with α at high Re. The present study shows a maximum of about 60% increase and a similar 60% reduction in wall drag over the entire range of conditions investigated.